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(12) **United States Patent**
Nabar et al.

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(45) **Date of Patent:** **Sep. 1, 2015**

(54) **METHOD AND APPARATUS FOR TRANSMITTING FIRST DATA STREAMS VIA RESPECTIVE TRANSMITTERS TO MULTIPLE CLIENTS STATIONS DURING A SAME PERIOD AND SUCCESSIVELY TRANSMITTING SECOND DATA STREAMS**

(2013.01); *H04B 7/0697* (2013.01); *H04L 65/608* (2013.01); *H04W 72/048* (2013.01); *H04W 28/0215* (2013.01); *H04W 74/06* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(71) Applicant: **Marvell World Trade Ltd.**, St. Michael (BB)

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(73) Assignee: **Marvell World Trade Ltd.**, St. Michael (BB)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(21) Appl. No.: **14/080,087**

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(22) Filed: **Nov. 14, 2013**

(Continued)

(65) **Prior Publication Data**

US 2014/0071973 A1 Mar. 13, 2014

Primary Examiner — Bob Phunkulh

Related U.S. Application Data

(57) **ABSTRACT**

(63) Continuation of application No. 13/430,170, filed on Mar. 26, 2012, now Pat. No. 8,588,144, which is a continuation of application No. 12/175,526, filed on Jul. 18, 2008, now Pat. No. 8,144,647.

An access point including a first transmitter and a second transmitter. The first transmitter is configured to (i) during a first window, transmit a first data stream to a first client station, and (ii) during a second window, transmit a second data stream to a second client station. The second transmitter is configured to: during the first window and while the first transmitter transmits the first data stream to the first client station, transmit a third data stream to a third client station; during a first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, refrain from transmitting a fourth data stream to a fourth client station; and subsequent to the first transmitter completing the transmission of the second data stream and during a second portion of the second window, transmit the fourth data stream to the fourth client station.

(60) Provisional application No. 60/950,429, filed on Jul. 18, 2007, provisional application No. 61/057,609, filed on May 30, 2008.

(51) **Int. Cl.**

H04W 4/00 (2009.01)

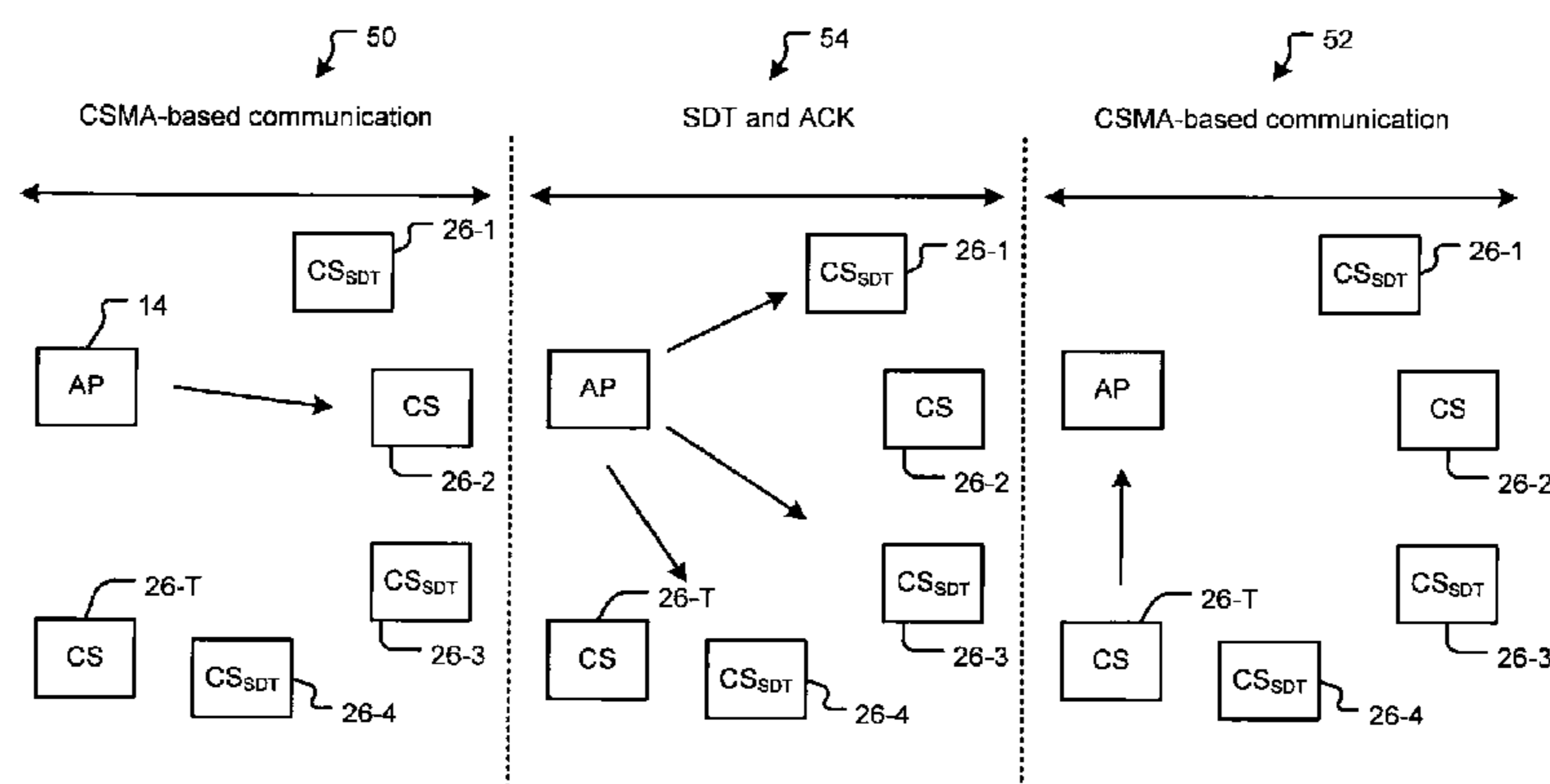
H04L 5/00 (2006.01)

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(52) **U.S. Cl.**

CPC *H04L 5/006* (2013.01); *H04B 7/0452*

18 Claims, 10 Drawing Sheets



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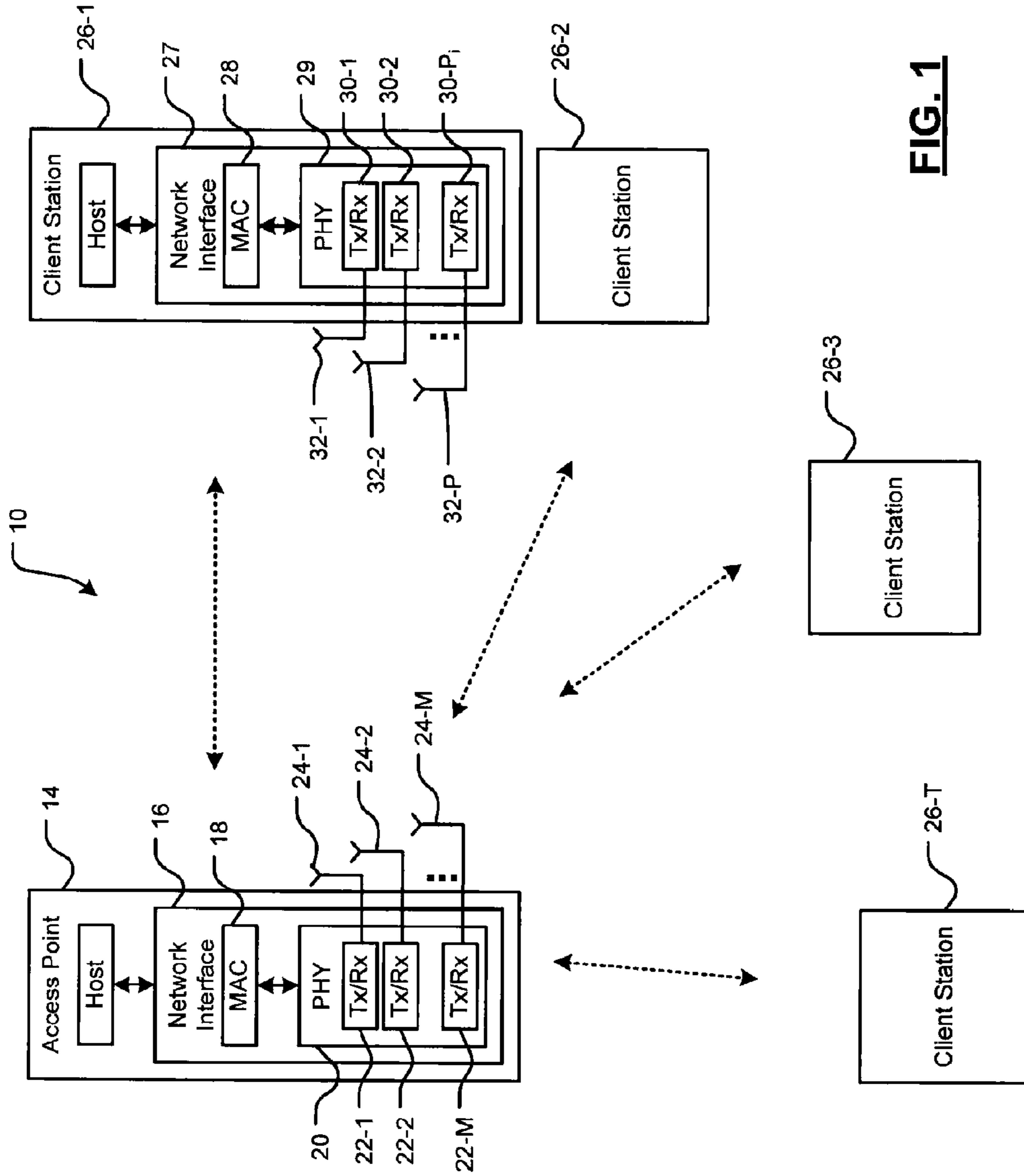


FIG. 1

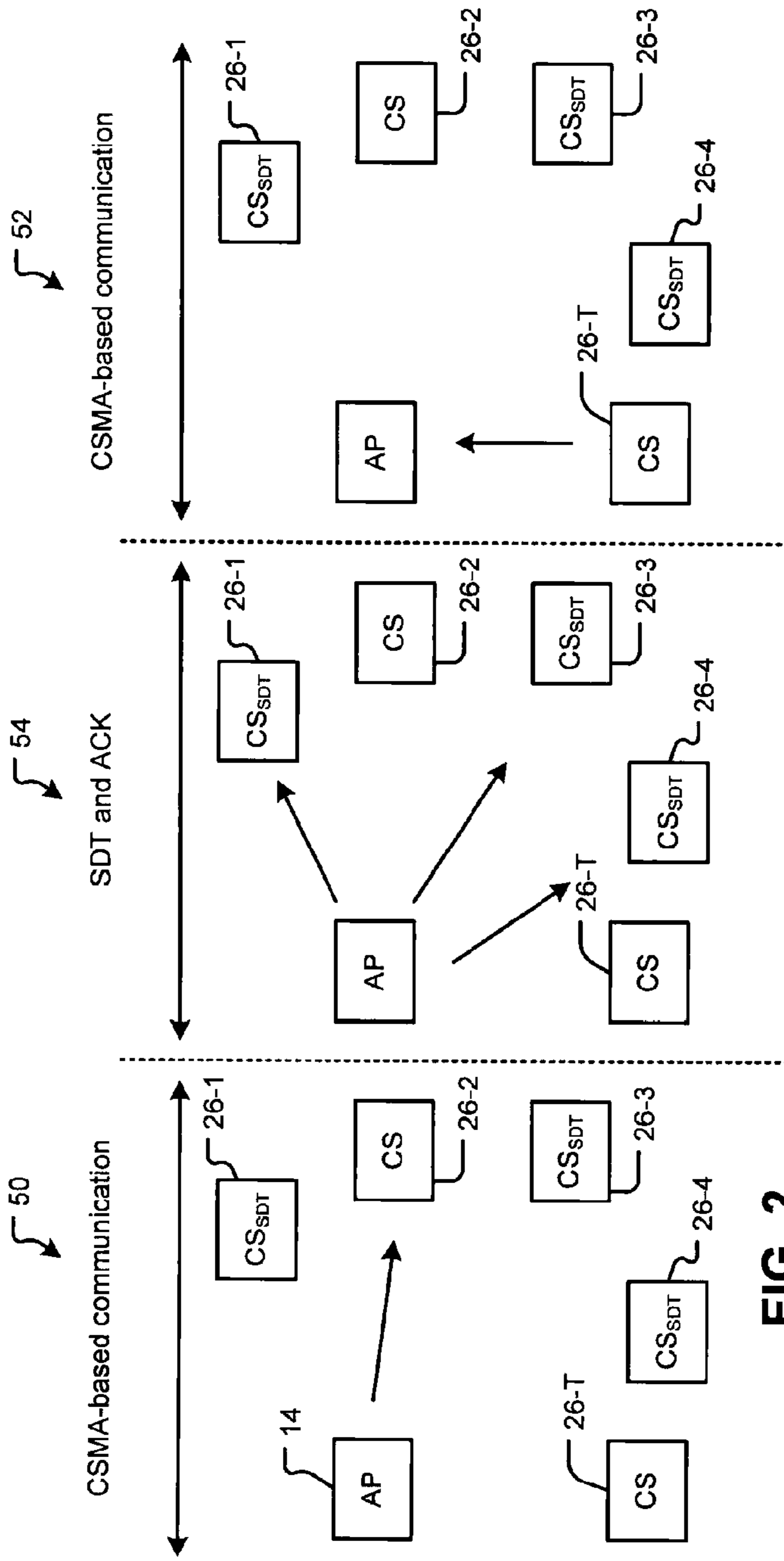


FIG. 2

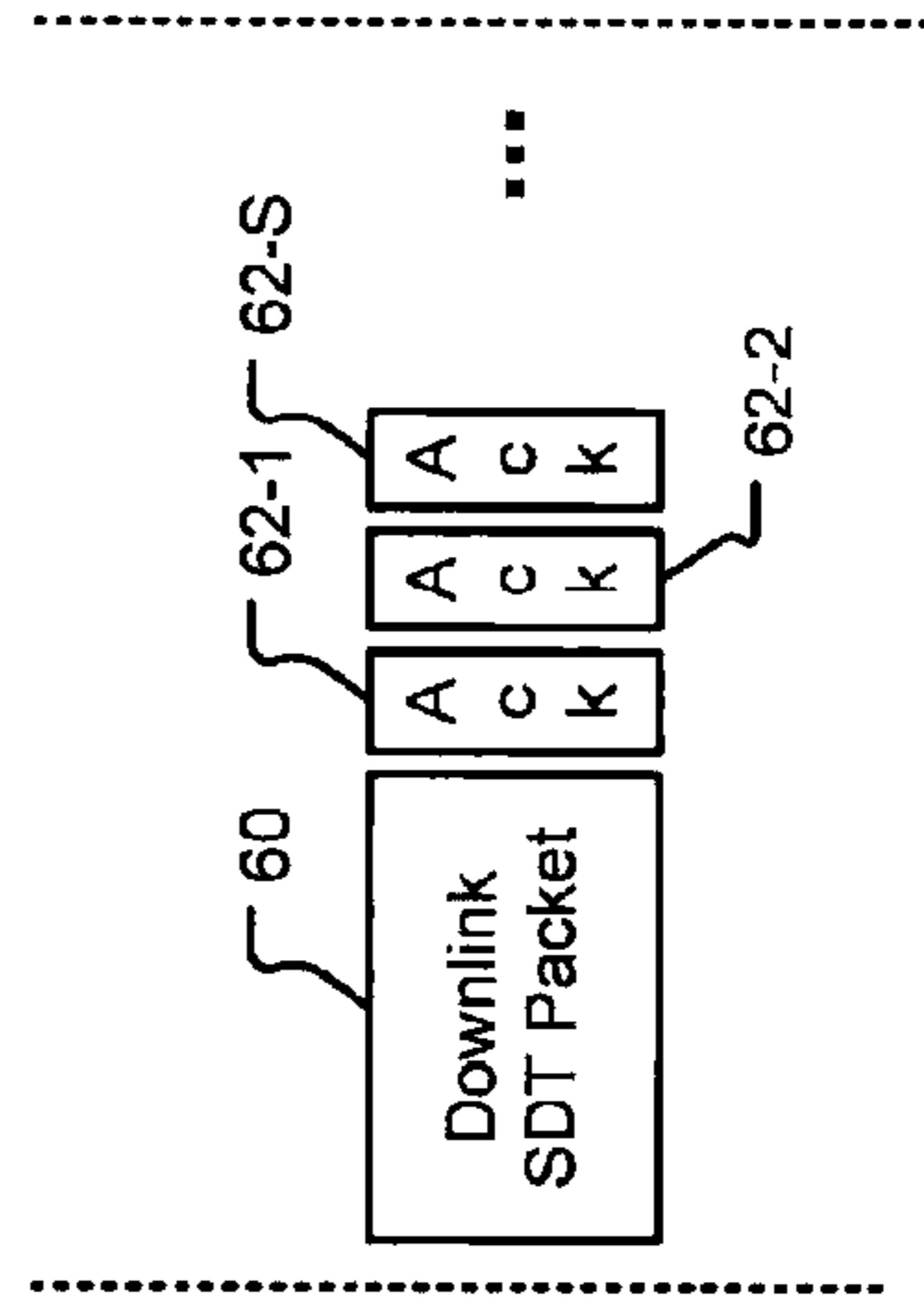


FIG. 3

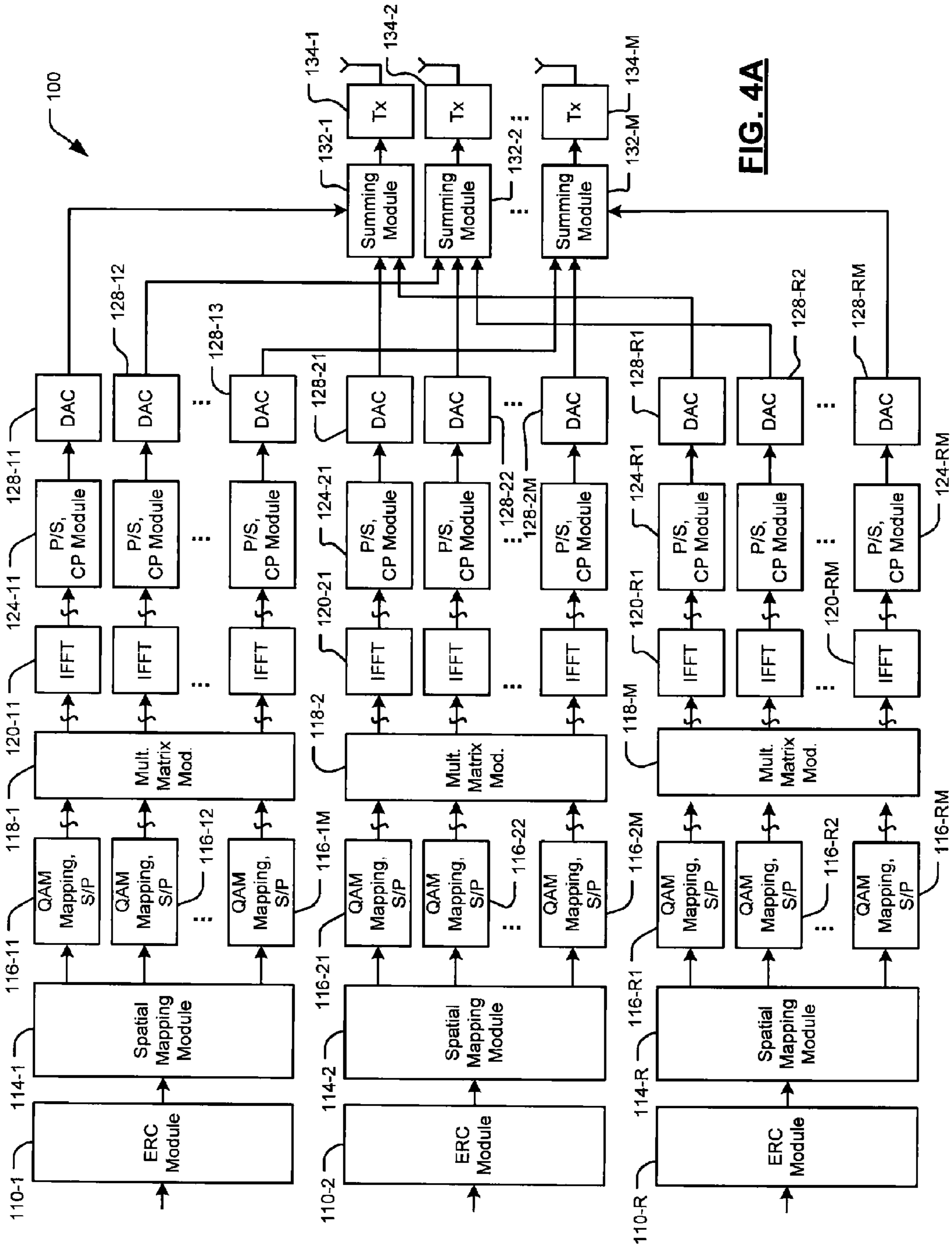
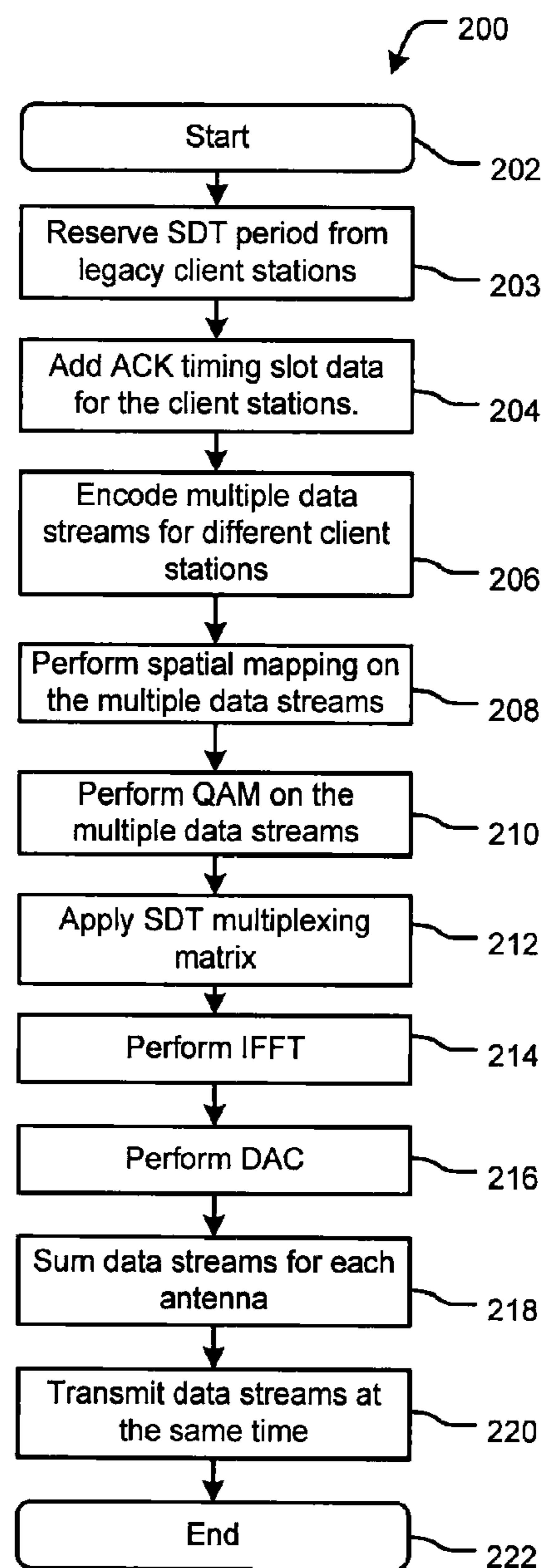


FIG. 4A

**FIG. 4B**

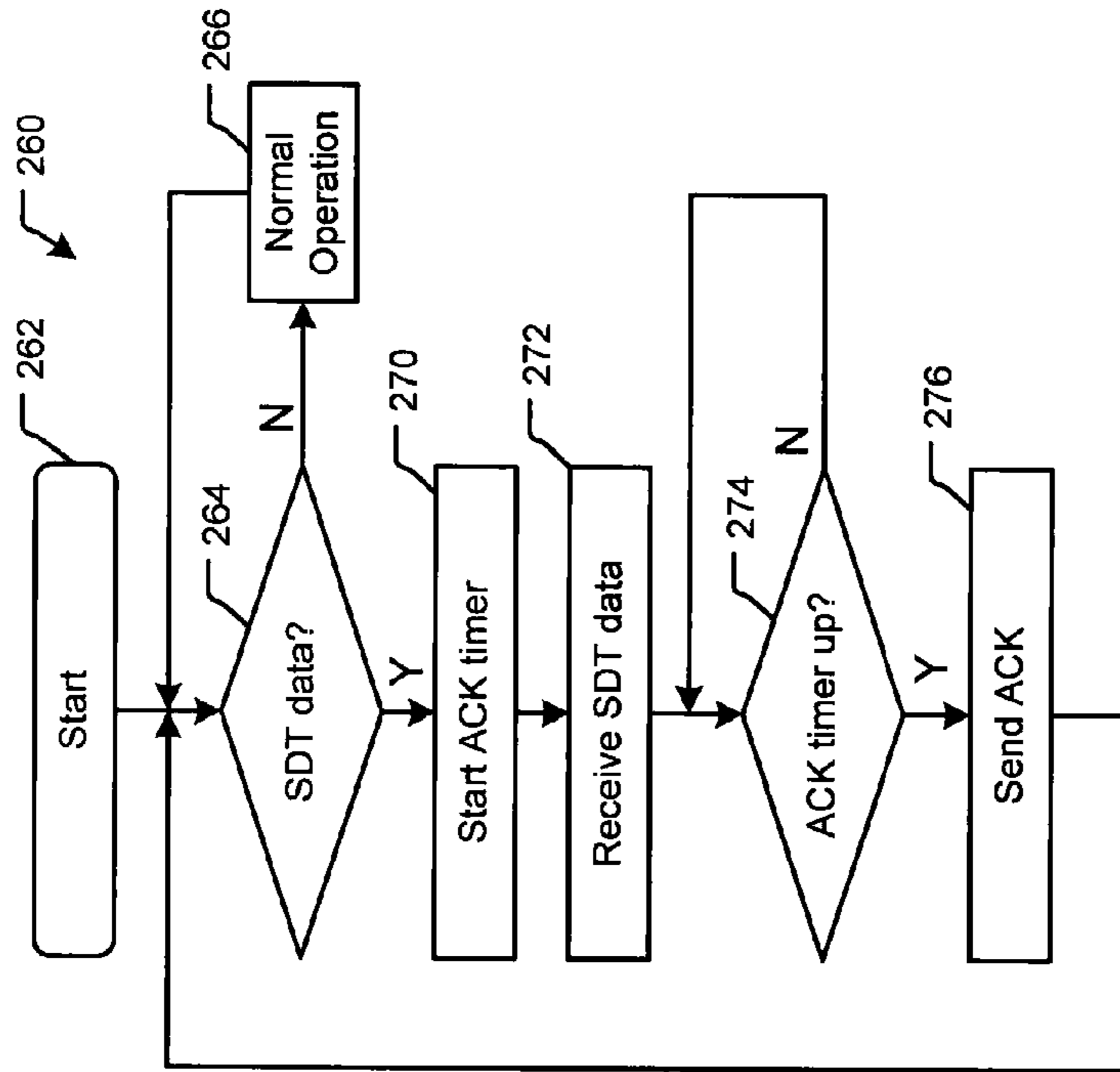


FIG. 5B

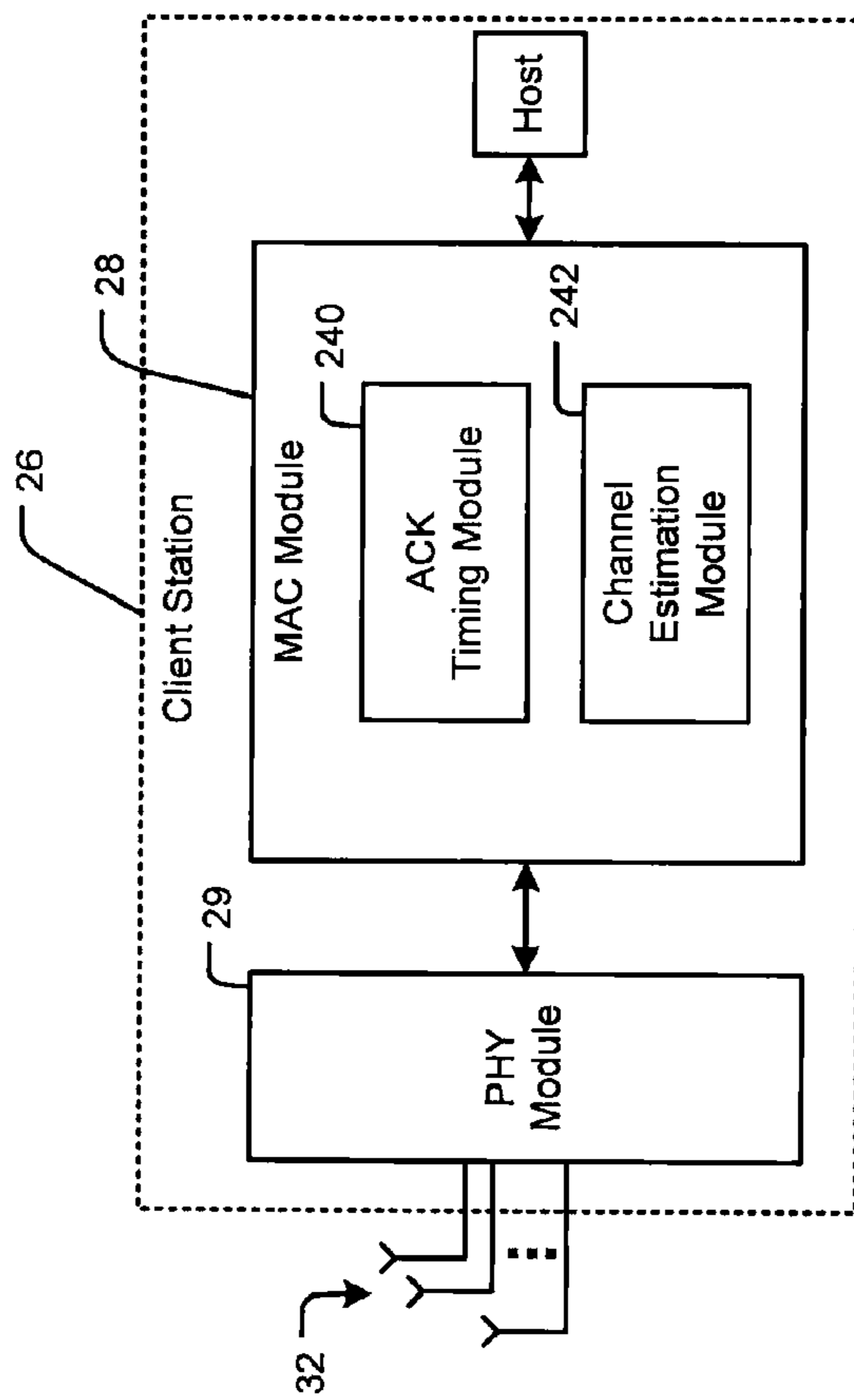


FIG. 5A

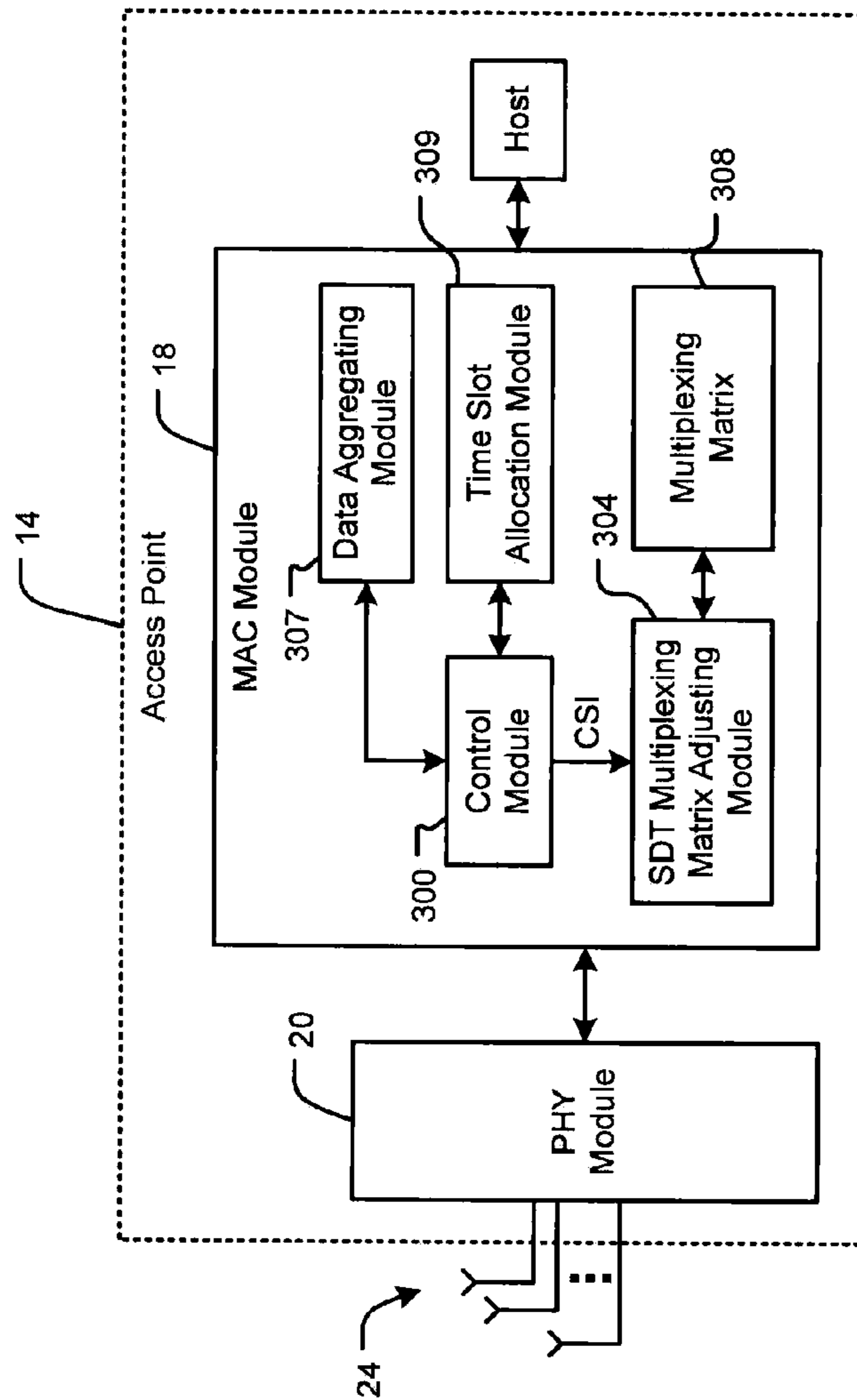


FIG. 6A

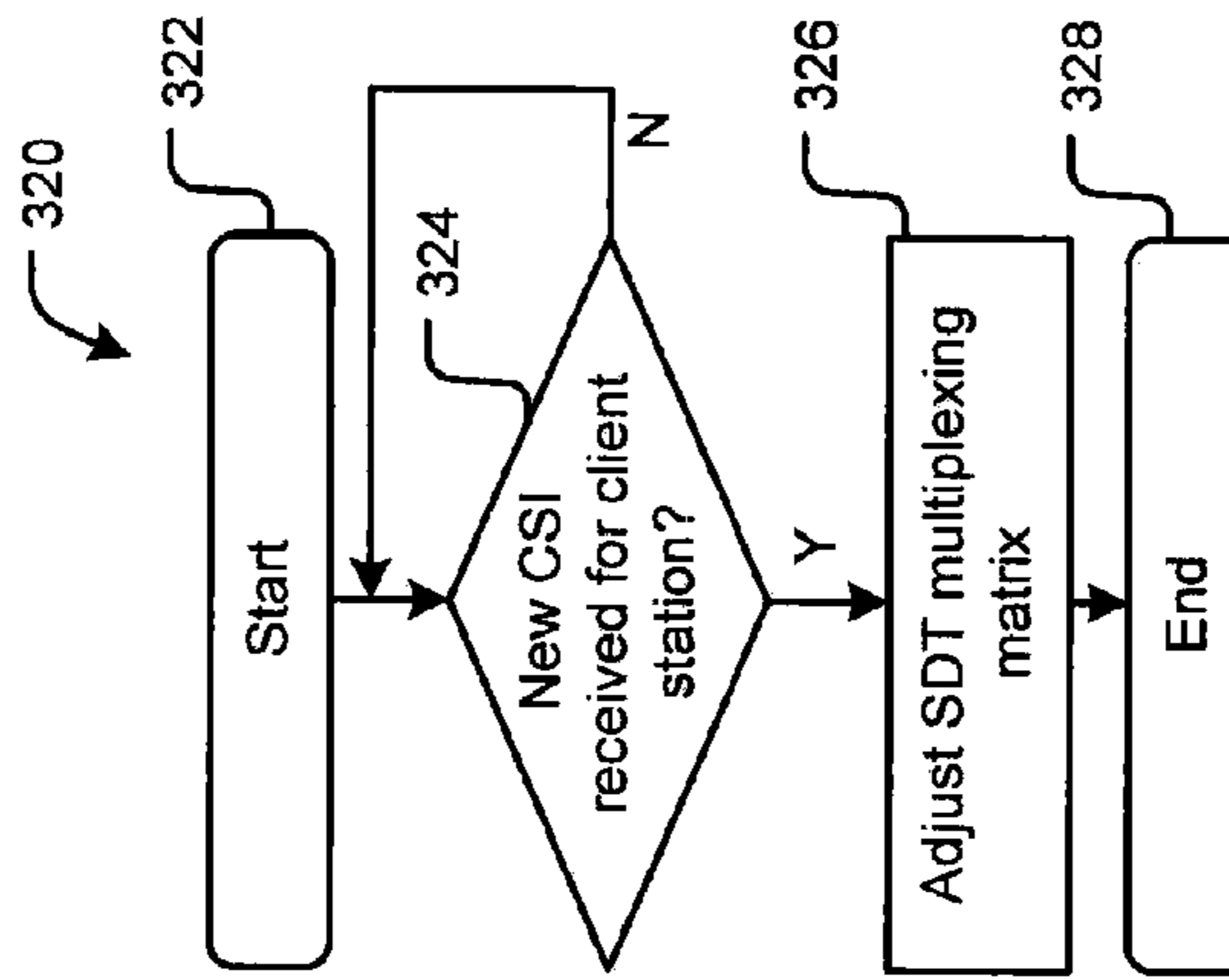


FIG. 6B

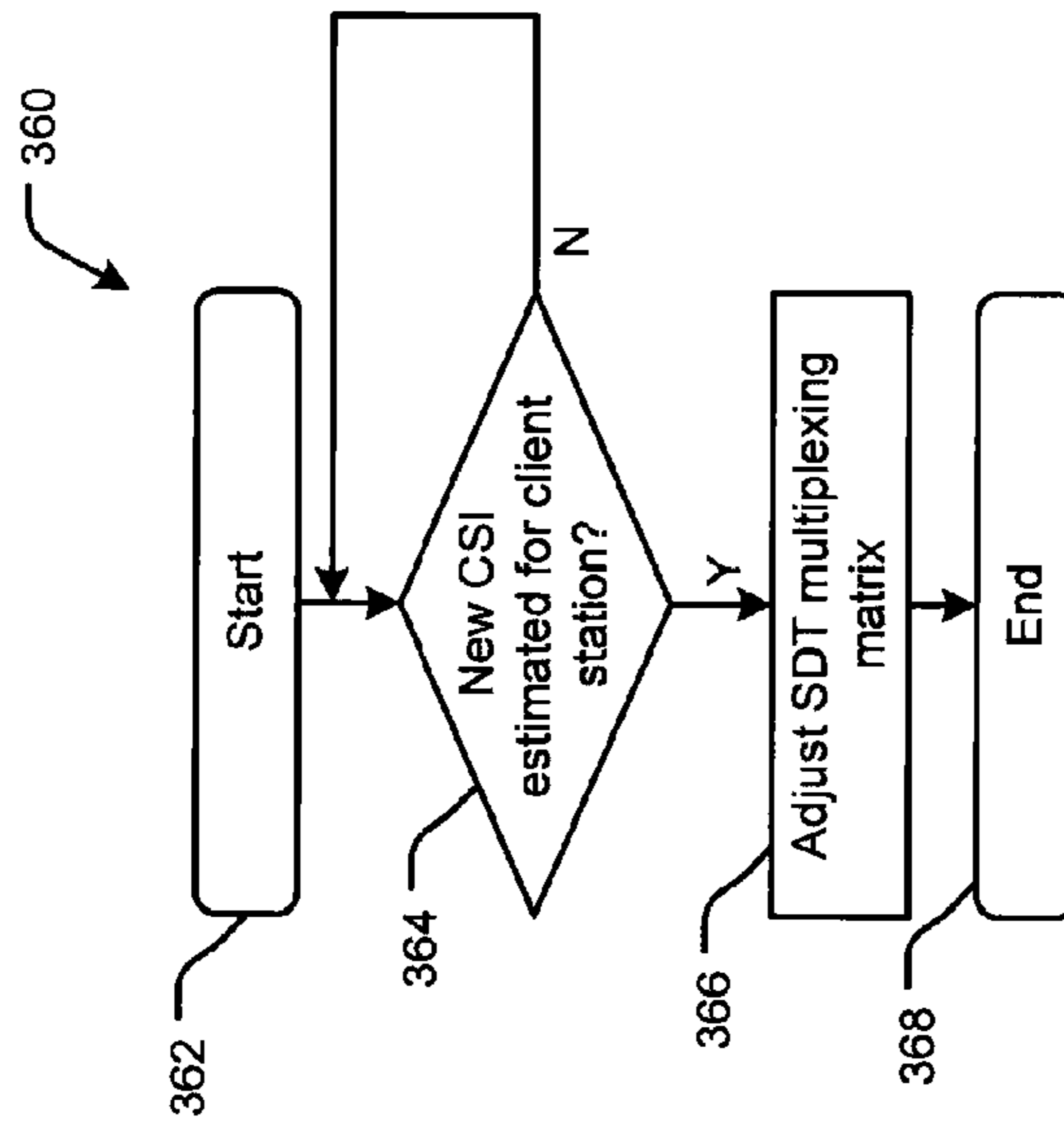


FIG. 7B

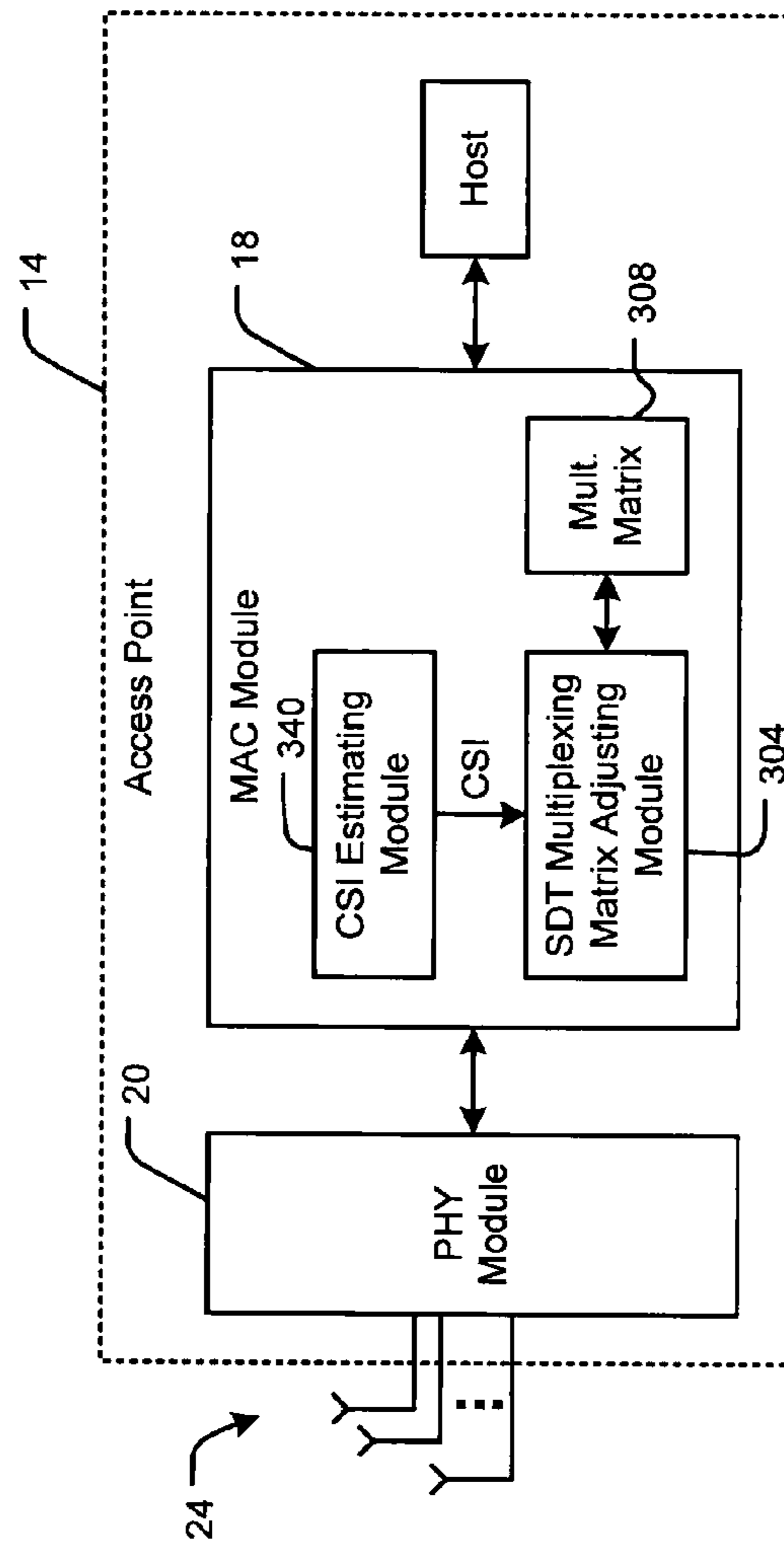


FIG. 7A

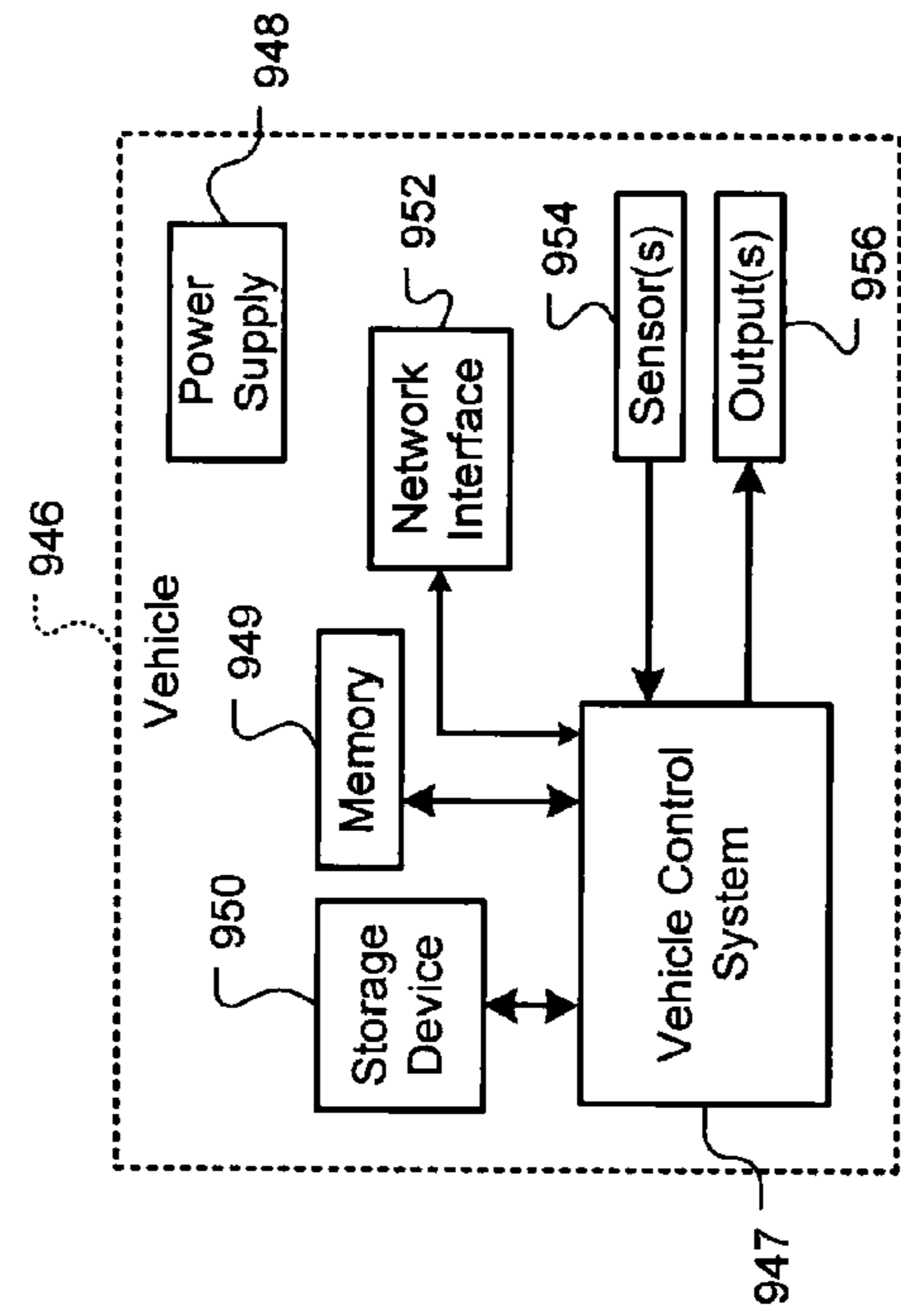


FIG. 8B

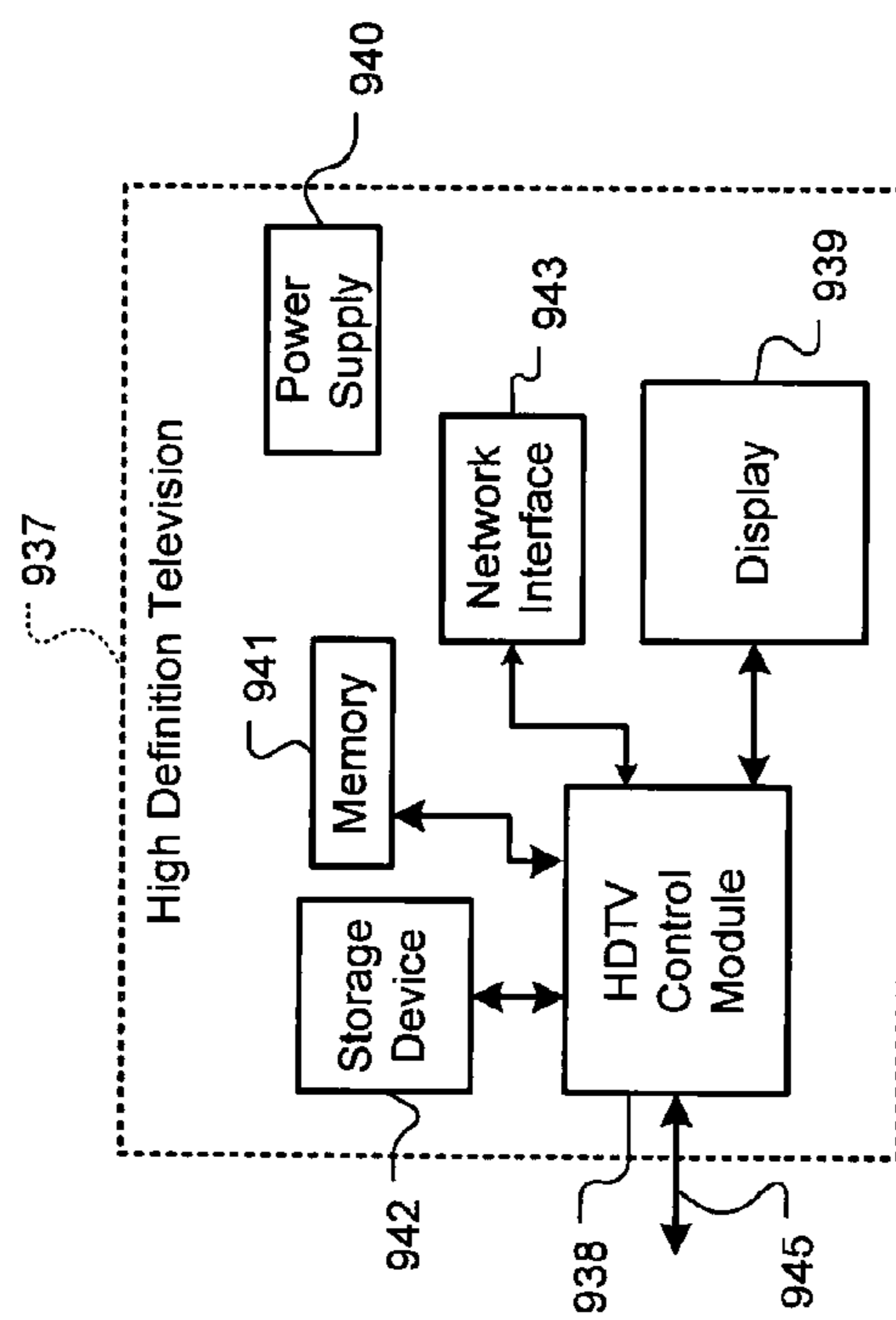


FIG. 8A

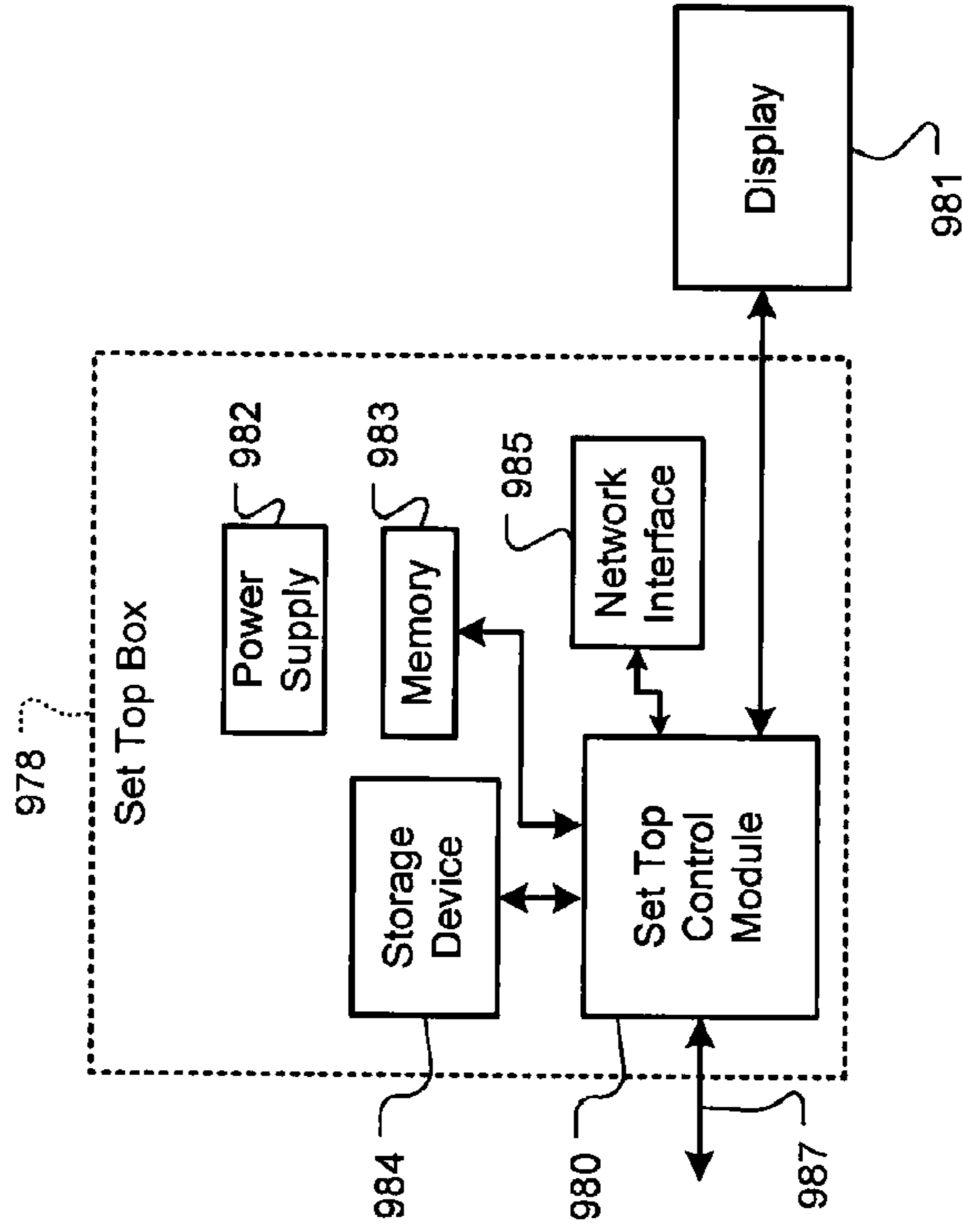


FIG. 8D

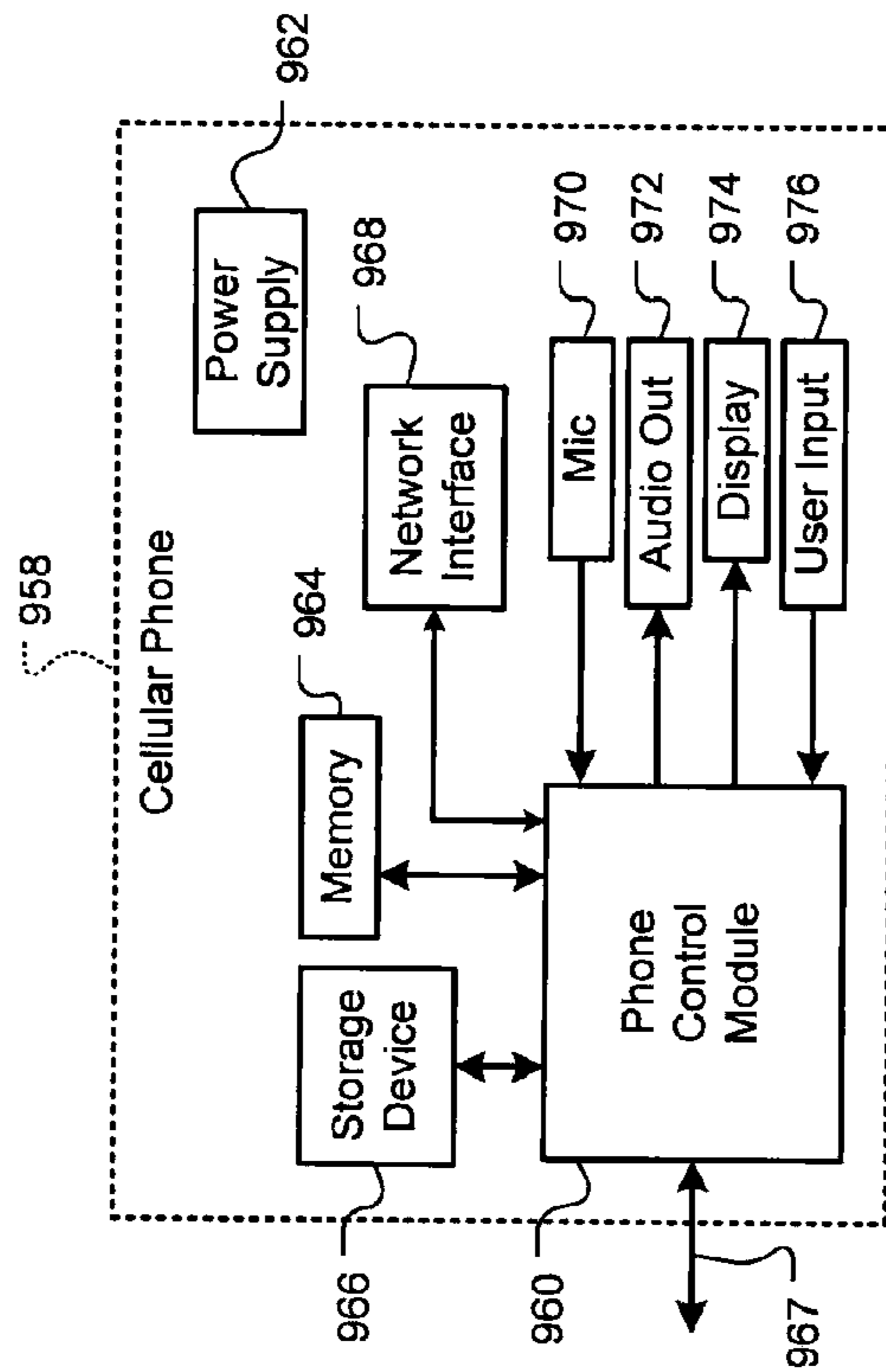


FIG. 8C

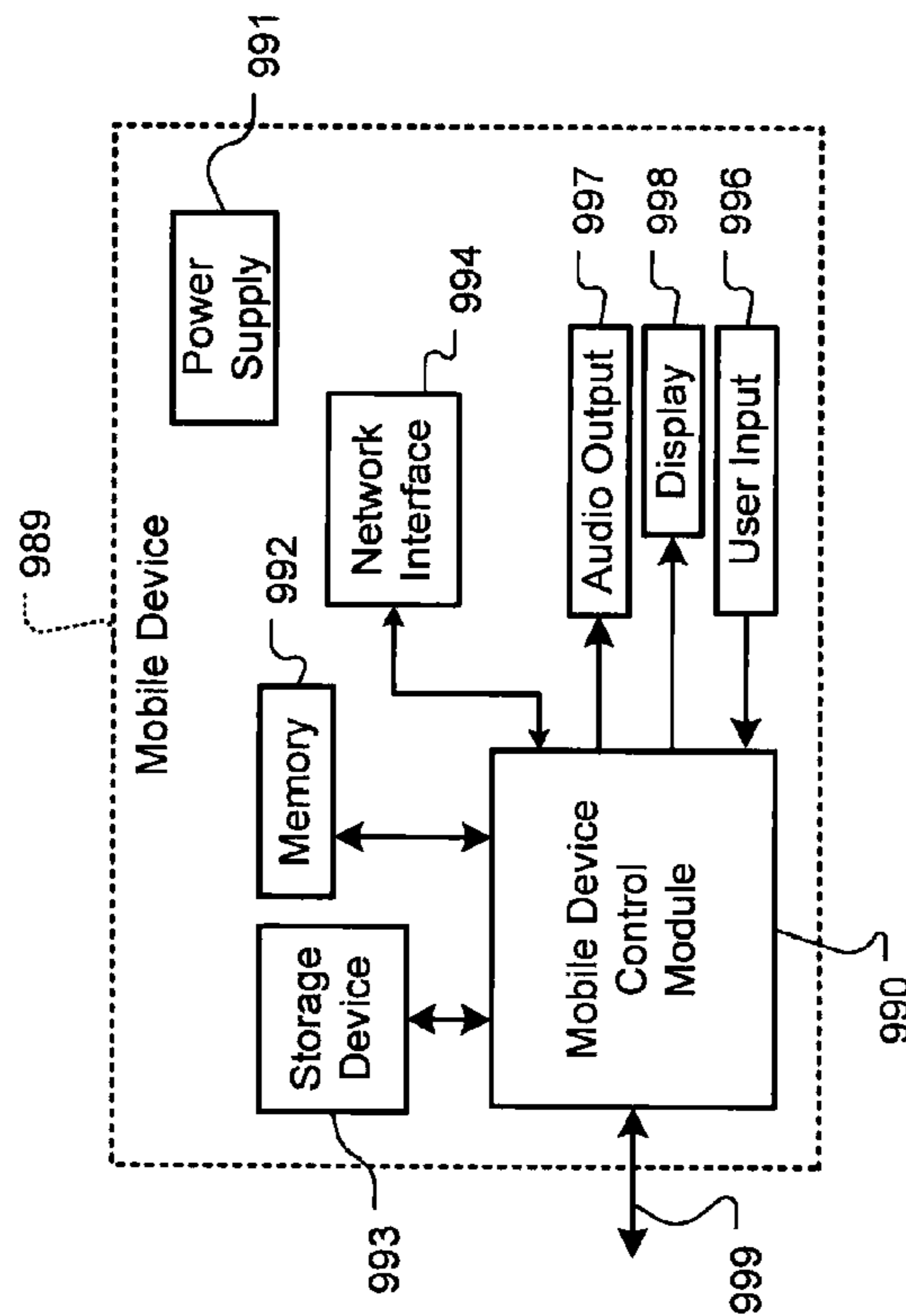


FIG. 8E

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**METHOD AND APPARATUS FOR
TRANSMITTING FIRST DATA STREAMS VIA
RESPECTIVE TRANSMITTERS TO
MULTIPLE CLIENT STATIONS DURING A
SAME PERIOD AND SUCCESSIVELY
TRANSMITTING SECOND DATA STREAMS**

**CROSS-REFERENCE TO RELATED
APPLICATIONS**

The present disclosure is a continuation of U.S. patent application Ser. No. 13/430,170 (now U.S. Pat. No. 8,588,144), filed Mar. 26, 2012, which is a continuation of U.S. patent application Ser. No. 12/175,526 (now U.S. Pat. No. 8,144,647), filed Jul. 18, 2008. This application claims the benefit of U.S. Provisional Application No. 60/950,429, filed on Jul. 18, 2007 and U.S. Provisional Application No. 61/057,609, filed on May 30, 2008. The entire disclosures of the applications referenced above are incorporated herein by reference.

FIELD

The present disclosure relates to wireless networks, and more particularly to wireless access points with simultaneous downlink transmission of independent data for multiple wireless client stations.

BACKGROUND

The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent the work is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

When operating in an infrastructure mode, Wireless Local Area Networks (WLANs) typically include an access point (AP) and one or more client stations. WLANs have evolved rapidly over the past decade. Development of WLAN standards such as IEEE §§802.11a/b/en has focused primarily on improving single-user peak data throughput. For example, IEEE §802.11b operates at a single-user peak throughput of 11 Mbps, IEEE §802.11a/g operates at a single-user peak throughput of 54 Mbps, and IEEE §802.11n operates at a single-user peak throughput of 600 Mbps.

In these WLANs, the AP transmits information to one client station at a time in a unicast mode. Alternatively, the same information may be transmitted to a group of client stations concurrently in a multicast mode. This approach reduces network efficiency because other client stations need to wait until the current client station or group of client stations is serviced. When transmitting the same information to the group of client stations, throughput may be limited by one of the client stations with the weakest reception.

SUMMARY

An access point is provided and includes a first transmitter and a second transmitter. The first transmitter is configured to (i) during a first window, transmit a first data stream to a first client station, and (ii) during a second window, transmit a second data stream to a second client station. The second transmitter is configured to: during the first window and while the first transmitter transmits the first data stream to the first client station, transmit a third data stream to a third client

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station; during a first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, refrain from transmitting a fourth data stream to a fourth client station; and subsequent to the first transmitter completing the transmission of the second data stream and during a second portion of the second window, transmit the fourth data stream to the fourth client station.

In other features, a method is provided and includes: during a first window, transmitting, via a first transmitter, a first data stream from an access point to a first client station; during a second window, transmitting, via the first transmitter, a second data stream from the access point to a second client station; and during the first window and while the first transmitter transmits the first data stream to the first client station, transmitting, via a second transmitter, a third data stream from the access point to a third client station. The method further includes: during a first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, refraining from transmitting a fourth data stream from the second transmitter to a fourth client station; and subsequent to the first transmitter completing the transmission of the second data stream to the second client station and during a second portion of the second window, transmitting, via the second transmitter, the fourth data stream from the access point to the fourth client station.

A wireless network device is provided and includes modulation modules. Each of the modulation modules is configured to (i) receive a data stream, and (ii) modulate the data stream to generate a modulated data stream. A matrix module is configured to (i) generate a multiplexing matrix based on channel conditions between the wireless network device and each of a plurality of client stations, and (ii) apply the multiplexing matrix to each of the modulated data streams to generate multiplexed data streams. The wireless network device also includes summing modules. Each of the summing modules is configured to sum at least two of the multiplexed data streams to generate a transmit data stream. A first transmitter is configured to transmit a first one of the transmit data streams during a downlink transmission period to a first one of the client stations. A second transmitter is configured to transmit a second one of the transmit data streams to a second one of the client stations while the first transmitter transmits the first one of the transmit data streams.

In other features, the wireless network device simultaneously transmits the M transmit data streams to R client stations. The wireless network device transmits a first one of the M transmit data streams to at least two client stations and a second one of the M transmit data streams to at least one client station. M receivers respectively receive R acknowledgements (ACKs) from the R client stations during R allocated time slots of the SDT period. Each of the R modulation modules includes a spatial mapping module that performs spatial mapping of one of the R independent data streams and that generates M spatial data streams; M modulation mapping modules that receive respective ones of the M spatial data streams and that output a set of tones; a multiplexing matrix module that applies the multiplexing matrix to the M sets of tones; and an inverse Fast Fourier Transform module that communicates with an output of the multiplexing matrix module.

In other features, each of the M modulation mapping modules includes a quadrature amplitude modulation (QAM) module. A multiplexing matrix module generates a respective multiplexing matrix based on channel conditions between the wireless network device and each of the R client stations. The

multiplexing matrix module determines a multiplexing matrix for one of the R client stations by minimizing signal energy of signals sent to others of the R client stations. The multiplexing matrix module determines a multiplexing matrix for one of the R client stations by maximizing a minimum signal-to-interference and noise ratio for the R client stations. The multiplexing matrix module determines the multiplexing matrix based on a signal-to-interference and noise ratio (SINR) of the R client stations.

In other features, the multiplexing matrix adjusts at least one of amplitude and phase for tones of the M transmit data streams. A transmitted signal vector s transmitted by the wireless network device is based on:

$$s = \sum_{i=1}^N W_i x_i$$

where x_i is an information vector intended for an i^{th} client station, W_i is the multiplexing matrix for the i^{th} client station.

In other features, a receiver receives channel state information (CSI) from the R client stations. Alternately, a channel condition estimator estimates channel state information based on signals received from the R client stations. The R independent data streams are arranged as subframes, frames, or packets.

A method includes receiving R independent data streams; modulating the R independent data streams; applying a multiplexing matrix to generate M modulated and multiplexed data streams, respectively, where R and M are integers greater than one; summing portions of each of the M modulated and multiplexed data streams to generate M transmit data streams; and simultaneously transmitting the M transmit data streams during a simultaneous downlink transmission (SDT) period.

In other features, the method includes transmitting the M transmit data streams to R client stations at the same time. The method includes transmitting a first one of the M transmit data streams to at least two client stations and a second one of the M transmit data streams to at least one client station. The method includes receiving R acknowledgements (ACKs) from the R client stations during R allocated time slots of the SDT period. The method includes performing spatial mapping of one of the R independent data streams and generating M spatial data streams; receiving respective ones of the M spatial data streams and outputting M sets of tones; applying the multiplexing matrix to the M sets of tones; and performing an inverse Fast Fourier Transform.

In other features, each of the M modulation mapping modules includes a quadrature amplitude modulation (QAM) module. The method includes generating a respective multiplexing matrix based on channel conditions between the wireless network device and each of the R client stations. The method includes determining a multiplexing matrix for one of the R client stations by minimizing signal energy of signals sent to others of the R client stations. The method includes determining a multiplexing matrix for one of the R client stations by maximizing a minimum signal-to-interference and noise ratio for the R client stations. The method includes determining the multiplexing matrix based on a signal-to-interference and noise ratio (SINR) of the R client stations. The method includes adjusting at least one of amplitude and phase for tones of the M transmit data streams. A transmitted signal vector s is based on:

$$s = \sum_{i=1}^N W_i x_i$$

where x_i is an information vector intended for an i^{th} client station, W_i is the multiplexing matrix for the i^{th} client station.

In other features, the method includes receiving channel state information (CSI) from the R client stations. The method includes estimating channel state information based on signals received from the R client stations. The R independent data streams are arranged as subframes, frames, or packets.

A wireless network device includes R modulation means for receiving R independent data streams, for modulating the R independent data streams, and for applying a multiplexing matrix to generate M modulated and multiplexed data streams, respectively, where R and M are integers greater than one. M summing means sum portions of each of the M modulated and multiplexed data streams to generate M transmit data streams. M transmitting means simultaneously transmit the M transmit data streams during a simultaneous downlink transmission (SDT) period.

In other features, the wireless network device simultaneously transmits the M transmit data streams to R client stations. The wireless network device transmits a first one of the M transmit data streams to at least two client stations and a second one of the M transmit data streams to at least one client station. M receiving means receive R acknowledgements (ACKs) from the R client stations during R allocated time slots, respectively, of the SDT period. Each of the R modulation means includes spatial mapping means for performing spatial mapping of one of the R independent data streams and for generating M spatial data streams; M modulation mapping means for receiving respective ones of the M spatial data streams and for outputting M sets of tones; multiplexing matrix means for applying the multiplexing matrix to the M sets of tones; and inverse Fast Fourier Transform means for communicating with an output of the multiplexing matrix means.

In other implementations, each of the M modulation mapping means performs quadrature amplitude modulation (QAM). Multiplexing matrix means generates a respective multiplexing matrix based on channel conditions between the wireless network device and each of the R client stations. The multiplexing matrix means determines a multiplexing matrix for one of the R client stations by minimizing signal energy of signals sent to others of the R client stations. The multiplexing matrix means determines a multiplexing matrix for one of the R client stations by maximizing a minimum signal-to-interference and noise ratio for the R client stations. The multiplexing matrix means determines the multiplexing matrix based on a signal-to-interference and noise ratio (SINR) of the R client stations. The multiplexing matrix adjusts at least one of amplitude and phase for tones of the M transmit data streams.

In other features, a transmitted signal vector s transmitted by the wireless network device is based on:

$$s = \sum_{i=1}^N W_i x_i$$

where x_i is an information vector intended for an i^{th} client station, W_i is the multiplexing matrix for the i^{th} client station.

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In other features, receiving means receives channel state information (CSI) from the R client stations.

In other features, channel condition estimating means estimates channel state information based on signals received from the R client stations. The R independent data streams are arranged as subframes, frames, or packets.

A computer program stored on a computer readable medium and executed by a processor includes receiving R independent data streams; modulating the R independent data streams; applying a multiplexing matrix to generate M modulated and multiplexed data streams, respectively, where R and M are integers greater than one; summing portions of each of the M modulated and multiplexed data streams to generate M transmit data streams; and simultaneously transmitting the M transmit data streams during a simultaneous downlink transmission (SDT) period.

In other features, the computer program further includes transmitting the M transmit data streams to R client stations at the same time. The computer program includes transmitting a first one of the M transmit data streams to at least two client stations and a second one of the M transmit data streams to at least one client station. The computer program includes receiving R acknowledgements (ACKs) from the R client stations during R allocated time slots of the SDT period.

In other features, the computer program includes performing spatial mapping of one of the R independent data streams and generating M spatial data streams; receiving respective ones of the M spatial data streams and outputting M sets of tones; applying the multiplexing matrix to the M sets of tones; and performing an inverse Fast Fourier Transform.

In other features, each of the M modulation mapping modules includes a quadrature amplitude modulation (QAM) module. The computer program includes generating a respective multiplexing matrix based on channel conditions between the wireless network device and each of the R client stations. The computer program includes determining a multiplexing matrix for one of the R client stations by minimizing signal energy of signals sent to others of the R client stations. The computer program includes determining a multiplexing matrix for one of the R client stations by maximizing a minimum signal-to-interference and noise ratio for the R client stations. The computer program includes determining the multiplexing matrix based on a signal-to-interference and noise ratio (SINR) of the R client stations. The computer program includes adjusting at least one of amplitude and phase for tones of the M transmit data streams.

In other features, the computer program includes transmitting a transmitted signal vector s based on:

$$s = \sum_{i=1}^N W_i x_i$$

where x_i is an information vector intended for an i^{th} client station, W_i is the multiplexing matrix for the i^{th} client station.

In other features, the computer program includes receiving channel state information (CSI) from the R client stations. The computer program includes estimating channel state information based on signals received from the R client stations. The R independent data streams are arranged as subframes, frames, or packets.

In still other features, the systems and methods described above are implemented by a computer program executed by one or more processors. The computer program can reside on

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a computer readable medium such as but not limited to memory, nonvolatile data storage, and/or other suitable tangible storage mediums.

Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. It should be understood that the detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. 1 is a functional block diagram of a WLAN including an access point (AP) and one or more client stations;

FIG. 2 is a timing diagram illustrating legacy windows and a simultaneous down link transmission (SDT) window;

FIG. 3 is a timing diagram illustrating a downlink STD packet and acknowledgments;

FIG. 4A is a functional block diagram of a transmit path of an AP;

FIG. 4B illustrates a method performed by the transmit path of an AP;

FIG. 5A illustrates an exemplary SDT client station;

FIG. 5B illustrates a method performed by the SDT client station of FIG. 5A;

FIG. 6A illustrates an exemplary AP;

FIG. 6B illustrates a method performed by the AP of FIG. 6A;

FIG. 7A illustrates an exemplary AP;

FIG. 7B illustrates a method performed by the AP of FIG. 7A;

FIG. 8A is a functional block diagram of a high definition television;

FIG. 8B is a functional block diagram of a vehicle control system;

FIG. 8C is a functional block diagram of a cellular phone;

FIG. 8D is a functional block diagram of a set top box; and

FIG. 8E is a functional block diagram of a mobile device.

DESCRIPTION

The following description is merely exemplary in nature and is in no way intended to limit the disclosure, its application, or uses. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A or B or C), using a non-exclusive logical or. It should be understood that steps within a method may be executed in different order without altering the principles of the present disclosure.

As used herein, the term module refers to an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality.

A wireless network device such as an access point (AP) according to the present disclosure transmits independent data streams to multiple client stations simultaneously (hereinafter simultaneous downlink transmission (SDT)). Using this approach increases the number of client stations that can be serviced by a single AP during a given time interval. In addition, in one aspect, the present disclosure takes advantage

of differing channel conditions of client stations associated with the AP to improve throughput.

Referring now to FIG. 1, a wireless local area network (WLAN) 10 includes an access point (AP) 14. The AP 14 includes a network interface 16 including a medium access control (MAC) module 18, a physical layer (PHY) module 20, M transceivers 22-1, 22-2, . . . , 22-M, and M antennas 24-1, 24-2, . . . , 24-M (collectively antennas 24), where M is an integer greater than one.

The WLAN 10 is associated with T client stations 26-1, 26-2, . . . , 26-T (collectively client stations 26), where T is an integer greater than one. R of the T client stations are SDT enabled, and (T-R) of the T client stations 26 may be legacy client stations that are not SDT enabled, where R is an integer less than or equal to T. Each of the client stations 26 may include a network interface 27 including a MAC module 28, a PHY module 29, P_i transceivers 30-1, 30-2, . . . , 30- P_i , and P_i antennas 32-1, 32-2, . . . , 32- P_i , where P_i is an integer greater than zero, and i corresponds to an i^{th} one of the T client stations 26. The client stations 26 may have different numbers of transceivers and antennas.

The AP 14 simultaneously transmits independent data to two or more of the R client stations 26 that are SDT enabled during an SDT window. For example, during a given SDT window, the AP 14 can transmit first data to a first SDT enabled client station while simultaneously transmitting second data to a second SDT enabled client data station. The SDT window includes a SDT portion and an acknowledgement portion following the SDT portion. For example only, the independent data may be arranged as packets, frames or sub-frames. In addition, the AP 14 may also transmit and receive data to/from the (T-R) legacy client stations 26 in a conventional manner (e.g., using a non-overlapping transmission approach) during a legacy window, such as a carrier sense multiple access (CSMA) window. Multi-user throughput is the sum of single-user throughputs of simultaneously serviced client stations 26. Multi-user throughput is based on the number of users that can be reliably serviced simultaneously. Increasing the number of transmit antennas tends to improve the ability of the AP 14 to simultaneously service more client stations 26.

The AP 14 and the client stations 26 may communicate using orthogonal frequency division multiplexing (OFDM) processing. A multiplexing matrix W for each of the client stations 26 may be determined based on channel conditions between the AP 14 and the client station 26 for each OFDM tone. For example, channel knowledge may be obtained at the AP 14 using explicit simultaneous downlink transmission (SDT) and/or implicit SDT. For explicit SDT, the client station 26 feeds back channel state information (CSI) to the AP 14. For implicit SDT, the AP 14 infers the CSI or channel conditions from signals received from the client station 26 on a reverse link. The implicit SDT approach may incorporate an initial calibration exchange so that the AP 14 can calculate an appropriate correction matrix to infer forward channel conditions from the reverse channel conditions. The client stations 26 may be simultaneously serviced using the above techniques. The multiplexing matrix W for a client station 26 may be refreshed periodically—e.g., when certain events occur and/or when client channel conditions change.

A signal (or vector) to be transmitted to each client station 26 may be multiplied by a corresponding multiplexing matrix W. The multiplexing matrix W for each client station 26 will generally be different from that for other client stations 26. The multiplexing matrix W will typically be a function of the channel conditions between the AP 14 and the respective ones of the client stations 26. Steered signal vectors corresponding

to the different client stations 26 are combined (e.g., added) and simultaneously transmitted by the AP 14 during an SDT window. The client stations 26 that receive the SDT data send an acknowledgement (ACK) during an allocated time slot during a later portion of the SDT window as will be described further below.

Each client station 26 receives signals intended for the client station 26 and signals intended for other client stations 26 as transformed by the channel. The multiplexing matrix W may be constructed based on interference avoidance and/or signal-to-interference and noise ratio (SINR) balancing. Interference avoidance attempts to minimize the amount of non-desired signal energy arriving at a client station 26. In the best case, interference avoidance ensures that signals intended for a particular client station 26 arrive only at the desired client station(s).

In addition to interference avoidance, signal-to-interference and noise ratio (SINR) balancing may be performed by the AP 14. SINR balancing involves designing multiplexing matrices to actively control the SINRs observed at the serviced client stations 26. For example, one SINR balancing approach may include maximizing the minimum SINR across serviced client stations 26.

A transmission signal model for a single tone for OFDM according to one implementation is set forth below:

$$s = \sum_{i=1}^N W_i x_i$$

where s is a transmitted signal vector for one tone, N is a number of simultaneously serviced users, x_i is an information vector ($T_i \times 1$, $T_i < P_i$) intended for the i^{th} user, W_i is a multiplexing matrix ($M \times T_i$) for the i^{th} user, M is a number of transmit antennas of the AP 14, and P_i is the number of receive antennas of the i^{th} client station 26. The transmission signal model extends to other OFDM tones. In addition, other modulation schemes and/or variants of OFDM may be used such as orthogonal OFDM multiple access (OFDMA).

For example only, the AP 14 determines the multiplexing matrix W for each of the client stations 26 based on channel conditions between the AP 14 and the respective client stations 26. The channel conditions for each of k tones of an OFDM signal may be as shown in Table I:

TABLE I

	Tones				
Client Station 1	H_1^1	H_2^1	H_3^1	...	H_k^1
Client Station 2	H_1^2	H_2^2	H_3^2	...	H_k^2
...
Client Station	H_1^S	H_2^S	H_3^S	...	H_k^S

H_1^1 represents the channel for a first tone of a first client station 26, H_2^1 represents the channel for second tone of the first client station 26, etc. The first tone received by the first client station 26 will be $H_1^1 [W_1^1 s_1 + W_1^2 s_2 + \dots + W_1^N s_N]$. The multiplexing matrix W may be selected to allow the first client station 26 to receive $W_1^1 W_1^1 s_1$ and to have the remaining signals s_2, s_3, \dots, s_N be in a null space for the first client station 26. Therefore when using the signal interference approach, the values of the multiplexing matrix W are selected such that $H_1^1 W_1^2 \approx 0, \dots, H_1^1 W_1^N \approx 0$. In other words, the multiplexing matrix W adjusts phases and amplitudes for these OFDM tones such that a null is created at the first client station 26.

That way, the first client station **26** can receive the intended signal s_1 without interference from other signals s_2, s_3, \dots, s_s intended for the other client stations **26**.

Power available to the AP **14** is typically constrained. When servicing multiple client stations **26** simultaneously, power available at the AP **14** may be allocated across multiple client stations **26**. This, in turn, affects the SINR observed at each of the client stations **26**. SDT tends to work best with flexible power management across the client stations **26**. For instance, a client station **26** with low data rate requirements may be allocated less power by the AP **14**. For instance, power may only be allocated to client stations **26** that have high probability of reliable reception (so as not to waste transmit power). Power may be adjusted in the corresponding multiplexing matrix W and/or after using other amplitude adjustment methods.

Independent data may also be simultaneously multicast to groups (independent across groups) of client stations **26**. SDT may also be combined with the concept of data aggregation. Frames transmitted from the AP **14** may be divided into subframes. Conventionally, each subframe is addressed to a single client station **26** or a group of client stations **26**. With SDT each sub-frame may carry independent information to client stations **26** or groups of client stations **26**.

Referring now to FIGS. **2** and **3**, exemplary legacy windows and SDT windows used by the AP **14** are shown. The AP **14** may transmit or receive data to/from legacy client stations **26** during legacy windows **50, 52**. For example, the legacy windows **50, 52** may be CSMA windows. During an SDT window **54**, the AP **14** sends SDT data **60** to multiple client stations **26** and then receives acknowledgements from the client stations **26**. During the SDT window **54**, other network devices are unable to transmit data. Time sufficient for the SDT window **54** may be arranged with the legacy client stations using MAC mechanisms provided by existing WLAN specifications.

In FIG. **3**, the downlink SDT data **60** may be followed by a period of acknowledgments (ACKs) **62-1, 62-2, \dots, 62-X** (collectively ACKs **62**) from SDT-enabled client stations **26** that received data during the SDT window **54**. The ACKs **62** may be transmitted after the SDT data based on a fixed schedule (e.g., using a time slot based approach). Allocation of the time slots may be performed by the AP **14**. For example, timing data based on the allocation of the time slots may be sent to the client stations **26** in the SDT downlink frame. However, the allocation of time for ACKs may be distributed using other approaches and/or at other times.

Referring now to FIGS. **4A** and **4B**, a transmit path **100** of the AP **14** is shown. The transmit path **100** includes encoder modules **110-1, 110-2, \dots, 110-R** (collectively encoder modules **110**) that receive R independent bit streams intended for R client stations **26**. The encoder modules **110** output encoded bit streams to spatial mapping modules **114-1, 114-2, \dots, 114-R** (collectively spatial mapping modules **114**), which perform spatial mapping.

Outputs of the spatial mapping modules **114** are input to quadrature amplitude modulation (QAM) mapping modules **116-11, 116-12, \dots, 116-RM** (collectively QAM mapping modules **116**), which perform QAM and serial-to-parallel (S/P) conversion. The QAM mapping modules **116** output OFDM tones that are input to multiplexing matrix modules **118-1, 118-2, \dots, 118-R** (collectively multiplexing matrix modules **118**). The multiplexing matrix modules **118** multiply the OFDM tones by a multiplexing matrix W as described herein.

Outputs of the multiplexing matrix modules **118** are input to inverse Fast Fourier Transform (IFFT) modules **120-11,**

120-12, \dots, 120-RM (collectively IFFT modules **120**). Outputs of the IFFT modules **120** are input to a parallel-to-serial (P/S) converter and cyclic prefix modules **124-11, 124-12, \dots, 124-RM** (collectively P/S and CP modules **124**). Outputs of the P/S and CP modules **124** are input to digital-to-analog converters (DACs) **128-11, 128-12, \dots, 128-RM** (collectively DACs **128**). Summing modules **132-1, 132-2, \dots, 132-M** sum corresponding outputs of the DACs **128** for each of the data streams and output the sum to transmitters **134-1, 134-2, \dots, 134-M** and associated antennas.

In FIG. **4B**, a method **200** performed by the transmit path **100** of the AP **14** is shown. The method begins with step **202** and proceeds to step **203**. In step **203**, the AP **14** may reserve a clear channel by instructing legacy client stations to refrain from transmitting during an SDT period. In step **204**, the AP **14** may add ACK timing slot data for the SDT-enabled client stations.

In step **206**, the transmit path **100** encodes multiple independent data streams for different client stations. In step **208**, spatial mapping is performed on the multiple data streams. In step **210**, quadrature amplitude modulation is performed on the multiple data streams. In step **212**, the SDT multiplexing matrix W is applied to the multiple data streams. In step **214**, an inverse Fast Fourier Transform (IFFT) is performed on the multiple data streams. In step **216**, the multiple data streams are converted from digital to analog format. The multiple data streams are summed in step **218** and transmitted at the same time in step **220**. The method ends with step **222**.

Referring now to FIGS. **5A** and **5B**, an exemplary client station **26** is shown. The client station **26** is SDT enabled and includes the MAC module **28** and the PHY module **29**. The MAC module **28** further includes an ACK timing module **240** and a channel estimation module **242**. The ACK timing module **240** receives an acknowledgment timing slot from the AP **14** as described above. The ACK timing module **240** determines when to transmit an ACK after receiving the SDT data.

In FIG. **5B**, a method performed by the client station **26** of FIG. **5A** is shown. The method **260** begins with step **262**. In step **264**, the client station **26** determines whether the SDT data **60** was received. If not, normal operation is performed in step **266** and the method returns to step **264**. When step **264** is true, an ACK timer is started in step **270**. The SDT data **60** is received in step **272**. The method determines whether the ACK timer is up (i.e., whether the timer has reached an end-point) in step **274**. If not, control returns to step **274**. When step **274** is true, control continues with step **276** and sends an ACK to the AP **14**.

Referring now to FIGS. **6A** and **6B**, an exemplary AP **14** is shown. The AP **14** includes the MAC module **18** and the PHY module **20** as described. The MAC module **18** includes a control module **300** that receives CSI from the client stations **26** that are SDT enabled. The client stations **26** may generate the CSI in a conventional manner. The CSI may include channel information for each of the tones. The control module **300** outputs the CSI to an SDT multiplexing matrix adjusting module **304**, which adjusts an SDT multiplexing matrix **308** for the tones.

The AP **14** may further include a data aggregation module **307** that selectively aggregates the SDT data into packets, frames and/or subframes. SDT data transmitted by the AP **14** may be divided into subframes by the data aggregation module **307**. Conventionally, each subframe is addressed to a single client station or a group of client stations. With SDT, each sub-frame may carry independent information to client stations and/or groups of client stations.

The AP **14** may further include a time slot allocation module **309** that assigns time slots for ACKs from the client

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stations 26. In some implementations, the time slot allocation module 309 inserts time allocation data into the SDT data for each client station 26.

In FIG. 6B, a method 320 performed by the AP 14 of FIG. 6A is shown. The method begins with step 322 and proceeds with step 324 where the AP 14 determines whether new CSI has been received from one of the client stations. If step 324 is false, control returns to step 324. If step 324 is true, the SDT matrix adjusting module 304 adjusts the SDT multiplexing matrix 308 in step 326. Control ends with step 328.

In FIGS. 7A and 7B, an exemplary AP 14 according to the present disclosure is shown. The AP 14 includes the MAC module 18 and the PHY module 20. The MAC module 18 includes channel estimating module 340. The channel estimating module 340 estimates CSI for the client stations 26. The channel estimating module 340 outputs the CSI to the SDT multiplexing matrix adjusting module 304, which adjusts the SDT multiplexing matrix 308 for the particular client station 26.

In FIG. 7B, a method 360 performed by the AP 14 of FIG. 7A is shown. The method begins with step 362 and proceeds with step 364 where the AP 14 determines whether new CSI has been estimated for a client station 26. If step 364 is false, control returns to step 364. In step 364 is true, the SDT multiplexing matrix adjusting module 304 adjusts the SDT multiplexing matrix 308 in step 366. Control ends with step 368.

The network interfaces may otherwise be compliant with IEEE standards—e.g., IEEE standards 802.11, 802.11a, 802.11b, 802.11g, 802.11h, 802.11n, 802.16, and/or 802.20, and/or Bluetooth, which are incorporated herein by reference in their entirety.

The present disclosure increases throughput by simultaneously transmitting independent data streams to multiple client stations. The present disclosure includes the use of multiple antennas at an AP to achieve SDT. The AP may consider a variety of criteria (interference avoidance, SINR balancing or other approach) to improve multi-user throughput. The AP may combine power allocation and SDT for maximal gains in throughput. The present disclosure also may combine SDT with multicast and data aggregation. A reserved time period during which legacy devices are forbidden from transmitting may be used during which SDT is conducted in the network. The reserved time interval may be divided into a time period for downlink of the SDT data and a time period for uplink ACKs from receiving client stations.

Referring now to FIGS. 8A-8E, various exemplary implementations incorporating the teachings of the present disclosure are shown. Referring now to FIG. 8A, the teachings of the disclosure can be implemented in a wireless network interface of a high definition television (HDTV) 937. The HDTV 937 includes an HDTV control module 938, a display 939, a power supply 940, memory 941, a storage device 942, a network interface 943, and an external interface 945. If the network interface 943 includes a wireless local area network interface, an antenna (not shown) may be included.

The HDTV 937 can receive input signals from the network interface 943 and/or the external interface 945, which can send and receive data via cable, broadband Internet, and/or satellite. The HDTV control module 938 may process the input signals, including encoding, decoding, filtering, and/or formatting, and generate output signals. The output signals may be communicated to one or more of the display 939, memory 941, the storage device 942, the network interface 943, and the external interface 945.

Memory 941 may include random access memory (RAM) and/or nonvolatile memory. Nonvolatile memory may

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include any suitable type of semiconductor or solid-state memory, such as flash memory (including NAND and NOR flash memory), phase change memory, magnetic RAM, and multi-state memory, in which each memory cell has more than two states. The storage device 942 may include an optical storage drive, such as a DVD drive, and/or a hard disk drive (HDD). The HDTV control module 938 communicates externally via the network interface 943 and/or the external interface 945. The power supply 940 provides power to the components of the HDTV 937.

Referring now to FIG. 8B, the teachings of the disclosure may be implemented in a wireless network interface of a vehicle 946. The vehicle 946 may include a vehicle control system 947, a power supply 948, memory 949, a storage device 950, and a network interface 952. If the network interface 952 includes a wireless local area network interface, an antenna (not shown) may be included. The vehicle control system 947 may be a powertrain control system, a body control system, an entertainment control system, an anti-lock braking system (ABS), a navigation system, a telematics system, a lane departure system, an adaptive cruise control system, etc.

The vehicle control system 947 may communicate with one or more sensors 954 and generate one or more output signals 956. The sensors 954 may include temperature sensors, acceleration sensors, pressure sensors, rotational sensors, airflow sensors, etc. The output signals 956 may control engine operating parameters, transmission operating parameters, suspension parameters, brake parameters, etc.

The power supply 948 provides power to the components of the vehicle 946. The vehicle control system 947 may store data in memory 949 and/or the storage device 950. Memory 949 may include random access memory (RAM) and/or nonvolatile memory. Nonvolatile memory may include any suitable type of semiconductor or solid-state memory, such as flash memory (including NAND and NOR flash memory), phase change memory, magnetic RAM, and multi-state memory, in which each memory cell has more than two states. The storage device 950 may include an optical storage drive, such as a DVD drive, and/or a hard disk drive (HDD). The vehicle control system 947 may communicate externally using the network interface 952.

Referring now to FIG. 8C, the teachings of the disclosure can be implemented in a wireless network interface of a cellular phone 958. The cellular phone 958 includes a phone control module 960, a power supply 962, memory 964, a storage device 966, and a cellular network interface 967. The cellular phone 958 may include a network interface 968, a microphone 970, an audio output 972 such as a speaker and/or output jack, a display 974, and a user input device 976 such as a keypad and/or pointing device. If the network interface 968 includes a wireless local area network interface, an antenna (not shown) may be included.

The phone control module 960 may receive input signals from the cellular network interface 967, the network interface 968, the microphone 970, and/or the user input device 976. The phone control module 960 may process signals, including encoding, decoding, filtering, and/or formatting, and generate output signals. The output signals may be communicated to one or more of memory 964, the storage device 966, the cellular network interface 967, the network interface 968, and the audio output 972.

Memory 964 may include random access memory (RAM) and/or nonvolatile memory. Nonvolatile memory may include any suitable type of semiconductor or solid-state memory, such as flash memory (including NAND and NOR flash memory), phase change memory, magnetic RAM, and

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multi-state memory, in which each memory cell has more than two states. The storage device **966** may include an optical storage drive, such as a DVD drive, and/or a hard disk drive (HDD). The power supply **962** provides power to the components of the cellular phone **958**.

Referring now to FIG. **8D**, the teachings of the disclosure can be implemented in a wireless network interface of a set top box **978**. The set top box **978** includes a set top control module **980**, a display **981**, a power supply **982**, memory **983**, a storage device **984**, and a network interface **985**. If the network interface **985** includes a wireless local area network interface, an antenna (not shown) may be included.

The set top control module **980** may receive input signals from the network interface **985** and an external interface **987**, which can send and receive data via cable, broadband Internet, and/or satellite. The set top control module **980** may process signals, including encoding, decoding, filtering, and/or formatting, and generate output signals. The output signals may include audio and/or video signals in standard and/or high definition formats. The output signals may be communicated to the network interface **985** and/or to the display **981**. The display **981** may include a television, a projector, and/or a monitor.

The power supply **982** provides power to the components of the set top box **978**. Memory **983** may include random access memory (RAM) and/or nonvolatile memory. Nonvolatile memory may include any suitable type of semiconductor or solid-state memory, such as flash memory (including NAND and NOR flash memory), phase change memory, magnetic RAM, and multi-state memory, in which each memory cell has more than two states. The storage device **984** may include an optical storage drive, such as a DVD drive, and/or a hard disk drive (HDD).

Referring now to FIG. **8E**, the teachings of the disclosure can be implemented in a wireless network interface of a mobile device **989**. The mobile device **989** may include a mobile device control module **990**, a power supply **991**, memory **992**, a storage device **993**, a network interface **994**, and an external interface **999**. If the network interface **994** includes a wireless local area network interface, an antenna (not shown) may be included.

The mobile device control module **990** may receive input signals from the network interface **994** and/or the external interface **999**. The external interface **999** may include USB, infrared, and/or Ethernet. The input signals may include compressed audio and/or video, and may be compliant with the MP3 format. Additionally, the mobile device control module **990** may receive input from a user input **996** such as a keypad, touchpad, or individual buttons. The mobile device control module **990** may process input signals, including encoding, decoding, filtering, and/or formatting, and generate output signals.

The mobile device control module **990** may output audio signals to an audio output **997** and video signals to a display **998**. The audio output **997** may include a speaker and/or an output jack. The display **998** may present a graphical user interface, which may include menus, icons, etc. The power supply **991** provides power to the components of the mobile device **989**. Memory **992** may include random access memory (RAM) and/or nonvolatile memory.

Nonvolatile memory may include any suitable type of semiconductor or solid-state memory, such as flash memory (including NAND and NOR flash memory), phase change memory, magnetic RAM, and multi-state memory, in which each memory cell has more than two states. The storage device **993** may include an optical storage drive, such as a DVD drive, and/or a hard disk drive (HDD). The mobile

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device may include a personal digital assistant, a media player, a laptop computer, a gaming console, or other mobile computing device.

Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims.

What is claimed is:

1. An access point comprising:

a first transmitter configured to (i) during a first window, transmit a first data stream to a first client station, and (ii) during a second window, transmit a second data stream to a second client station;

a second transmitter configured to

during the first window and while the first transmitter transmits the first data stream to the first client station, transmit a third data stream to a third client station, during a first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, refrain from transmitting a fourth data stream to a fourth client station, and subsequent to the first transmitter completing the transmission of the second data stream to the second client station and during a second portion of the second window, transmit the fourth data stream to the fourth client station; and

a control module configured to determine whether the first client station and the third client station are enabled for simultaneous downlink transmission,

wherein

the first transmitter is configured to, based on whether the first client station is enabled for simultaneous downlink transmission during the first window, transmit the first data stream to the first client station, and the second transmitter is configured to, based on whether the third client station is enabled for simultaneous downlink transmission during the first window, transmit the third data stream to the third client station.

2. The access point of claim 1, wherein:

the first client station is separate from the third client station; and

the second client station is separate from the fourth client station.

3. An access point comprising:

a first transmitter configured to (i) during a first window, transmit a first data stream to a first client station, and (ii) during a second window, transmit a second data stream to a second client station; and

a second transmitter configured to

during the first window and while the first transmitter transmits the first data stream to the first client station, transmit a third data stream to a third client station, during a first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, refrain from transmitting a fourth data stream to a fourth client station, and subsequent to the first transmitter completing the transmission of the second data stream to the second client station and during a second portion of the second window, transmit the fourth data stream to the fourth client station,

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wherein

the first client station and the third client station are enabled for simultaneous downlink transmission during the first window, and

the second client station and the fourth client station are not enabled for simultaneous downlink transmission during the second window.

4. An access point comprising:

a first transmitter configured to (i) during a first window, transmit a first data stream to a first client station, and (ii) during a second window, transmit a second data stream to a second client station; and

a second transmitter configured to

during the first window and while the first transmitter transmits the first data stream to the first client station, transmit a third data stream to a third client station, during a first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, refrain from transmitting a fourth data stream to a fourth client station, and subsequent to the first transmitter completing the transmission of the second data stream to the second client station and during a second portion of the second window, transmit the fourth data stream to the fourth client station,

wherein the second transmitter is configured to

during the first window and while the first transmitter transmits the first data stream to the first client station, transmit the third data stream to the first client station, during the first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, refrain from transmitting the fourth data stream to the second client station, and

subsequent to the first transmitter completing transmission of the second data stream to the second client station and during the second portion of the second window, transmit the fourth data stream to the second client station.

5. An access point comprising:

a first transmitter configured to (i) during a first window, transmit a first data stream to a first client station, and (ii) during a second window, transmit a second data stream to a second client station;

a second transmitter configured to

during the first window and while the first transmitter transmits the first data stream to the first client station, transmit a third data stream to a third client station, during a first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, refrain from transmitting a fourth data stream to a fourth client station, and subsequent to the first transmitter completing the transmission of the second data stream to the second client station and during a second portion of the second window, transmit the fourth data stream to the fourth client station;

a first matrix module configured to (i) receive a first plurality of modulated data streams, (ii) generate a first matrix based on channel conditions between the access point and one of the first client station and the second client station, and (ii) apply the first matrix to the first plurality of modulated data streams to generate a first multiplexed data stream and a second multiplexed data stream;

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a first summing module configured to, based on the first multiplexed data stream, generate the first data stream and the second data stream; and

a second summing module configured to, based on the second multiplexed data stream, generate the third data stream and the fourth data stream.

6. The access point of claim 5, further comprising:

a second matrix module configured to (i) receive a second plurality of modulated data streams, (ii) generate a second matrix based on channel conditions between the access point and one of the third client station and the fourth client station, and (ii) apply the second matrix to the second plurality of modulated data streams to generate a third multiplexed data stream and a fourth multiplexed data stream;

the first summing module is configured to sum the first multiplexed data stream and the third multiplexed data stream to generate each of the first data stream and the second data stream; and

the second summing module is configured to sum the second multiplexed data stream and the fourth multiplexed data stream to generate each of the third data stream and the fourth data stream.

7. The access point of claim 5, wherein the first matrix module is configured to generate the first matrix for the first client station by minimizing signal energy of a signal sent to the third client station.

8. The access point of claim 5, wherein the first matrix module is configured to generate the first matrix for the first client station by maximizing a signal-to-interference and noise ratio for the first client station and the third client station.

9. The access point of claim 5, wherein the first matrix module is configured to, for tones of the first transmit data stream and the third transmit data stream, adjust at least one of amplitude or phase.

10. The access point of claim 5, wherein one of the first transmitter and the second transmitter is configured to transmit a signal vector s , where:

$$s = \sum_{i=1}^N W_i x_i;$$

x_i is an information vector for an i^{th} one of a plurality of client stations, the plurality of client stations comprise the first client station and the third client station; and W_i is a matrix for the i^{th} one of the plurality of client stations.

11. A method comprising:

during a first window, transmitting, via a first transmitter, a first data stream from an access point to a first client station;

during a second window, transmitting, via the first transmitter, a second data stream from the access point to a second client station;

during the first window and while the first transmitter transmits the first data stream to the first client station, transmitting, via a second transmitter, a third data stream from the access point to a third client station;

during a first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, refraining from transmitting a fourth data stream from the second transmitter to a fourth client station;

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subsequent to the first transmitter completing the transmission of the second data stream to the second client station and during a second portion of the second window, transmitting, via the second transmitter, the fourth data stream from the access point to the fourth client station; and

determining whether the first client station and the third client station are enabled for simultaneous downlink transmission, wherein

based on whether the first client station is enabled for simultaneous downlink transmission during the first window, the first data stream is transmitted, via the first transmitter, to the first client station, and

based on whether the third client station is enabled for simultaneous downlink transmission during the first window, the third data stream is transmitted, via the second transmitter, to the third client station.

12. The method of claim **11**, wherein:
the first client station and the third client station are enabled for simultaneous downlink transmission during the first window; and
the second client station and the fourth client station are not enabled for simultaneous downlink transmission during the second window.

13. The method of claim **11**, wherein:
the first client station is separate from the third client station; and
the second client station is separate from the fourth client station.

14. The method of claim **11**, wherein:
during the first window and while the first transmitter transmits the first data stream to the first client station, the third data stream is transmitted, via the second transmitter, to the first client station;

during the first portion of the second window and while the first transmitter is transmitting the second data stream to the second client station, the fourth data stream is not transmitted, via the second transmitter, to the second client station; and

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subsequent to the first transmitter completing transmission of the second data stream to the second client station and during the second portion of the second window, the fourth data stream is transmitted, via the second transmitter, to the second client station.

15. The method of claim **11**, further comprising:
receiving a first plurality of modulated data streams;
generating a first matrix based on channel conditions between the access point and one of the first client station and the second client station;
applying the first matrix to the first plurality of modulated data streams to generate a first multiplexed data stream and a second multiplexed data stream;
based on the first multiplexed data stream, generating the first data stream and the second data stream; and
based on the second multiplexed data stream, generating the third data stream and the fourth data stream.

16. The method of claim **15**, further comprising:
receiving a second plurality of modulated data streams;
generating a second matrix based on channel conditions between the access point and one of the third client station and the fourth client station;
applying the second matrix to the second plurality of modulated data streams to generate a third multiplexed data stream and a fourth multiplexed data stream;
summing the first multiplexed data stream and the third multiplexed data stream to generate each of the first data stream and the second data stream; and
summing the second multiplexed data stream and the fourth multiplexed data stream to generate each of the third data stream and the fourth data stream.

17. The method of claim **15**, wherein the first matrix is generated for the first client station by minimizing signal energy of a signal sent to the third client station.

18. The method of claim **15**, wherein the first matrix is generated for the first client station by maximizing a signal-to-interference and noise ratio for the first client station and the third client station.

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